10.0 ENTRY SYSTEMS PANEL DELIBERATIONS

The Entry Systems Panel was chaired by Don Rummler, LaRC and Dan Rasky, ARC. As requested, each panel participant prior to the workshop prepared and delivered presentations to:

1) Identify technology needs
2) Assess current programs
3) Identify technology gaps
4) Identify highest payoff areas R&D

Participants presented background on the entry systems R&D efforts and operations experiences for the Space Shuttle Orbiter. These participants represented NASA Centers involved in research (Ames Research Center), development (Johnson Space Center), and operations (Kennedy Space Center) and the Shuttle Orbiter prime contractor. The presentations lead to the discovery of several lessons learned.

10.1 Technology Needs

Three key technology drivers for all anticipated vehicles and missions were identified:

- Improved TPS performance for safety/reliability
- Lower operating costs
- Increased vehicle capability and supportability

These technology drivers lead to the identification of fourteen high-payoff technology needs as discussed in the following sections.

Metallic TPS Concepts

Metallic concepts offer the potential for more flexibility in adverse weather environments (moisture, impact, and lightning strikes), are mechanically attached to the structure, and are weight-compatible with ceramic, ceramic matrix composite, and carbon-carbon TPS concepts. However, metallics lack the certification testing and flight experience of other TPS systems. Also, little R&D has been conducted in the U.S. in the last decade on this class of TPS. Coatings having high temperature resistance and emissivity, moisture resistance, and aerodynamic/vibroacoustic stability should be improved. High-temperature, flexible adhesives that take advantage of warm (high-temperature composite) structures should be developed. Finally, all improvements should be demonstrated through appropriate tests of integrated TPS/structural systems.

Research to provide improvements in high-temperature properties, coatings for low catalytic and high emissivity, and oxidation and corrosion resistance should be pursued. To supplement this technology base, tests should be conducted to verify thermal performance, effectiveness of preventing hot gas flow to the interior, and tolerance to acoustic loads.

Flexible Ceramic TPS Concepts

Flexible insulations such as felts, quilts, and woven blankets offer excellent benefits such as low weight, minimum certification investment required for improved concepts due to flight experience on the Shuttle Orbiter, and potentially lower life cycle costs. However, these concepts are currently temperature limited (FRSI - 700°F, AFRSI - 1500°F). Available high-temperature fibers can significantly increase the temperature capability for this class of TPS.

Inorganic/organic yarns, fabrics, felts and blends should be developed and evaluated using the existing high-temperature fibers. Fabrication methods to achieve lower cost, develop flexible coatings having high temperature resistance and emissivity, moisture resistance, and aerodynamic/vibroacoustic stability should be improved. High-temperature, flexible adhesives to take advantage of warm (high-temperature composites) structures should be developed. Finally, all improvements should be demonstrated through appropriate tests of integrated TPS/structural systems.

Toughened Ceramic TPS Concepts

A strong motivation exists to continue with the current RSI-type TPS, if its durability and strength and temperature capabilities can be improved, because of the extensive certification data and flight experience available. Higher-strength RSI could lead to direct-bond applications, which would eliminate the need for a strain isolation pad (SIP). Advanced fibers suggest the possibility of developing more refractory RSI materials.

A program should be initiated to identify and develop toughened coatings and advanced fibers. These new materials would require characterization and thermal response tests in arc-jets. The best candidates would then be subjected to systems tests that demonstrate acceptable performance for use on future space transportation vehicles.

Advanced Carbon-Carbon TPS

Reinforced carbon-carbon (RCC) leading edges and nose caps on the Shuttle Orbiter have no flight anomalies. The advanced carbon-carbon (ACC) materials have demonstrated up to five times the strength of RCC, and fabrication of a large, built-up structure of ACC has been demonstrated. Thin, structural, oxidation-resistant carbon-carbon (ORCC) composites for both TPS and structural applications offer the potential of low weight, durability, low maintenance and repair, and can be tailored for various service environments. The major deficiency is long-life oxidation protection. To eliminate this deficiency, improved methods for oxidation protection, including coatings, inhibitors, sealants, and glazes should be developed. Critical, life-limiting tests should be conducted to demonstrate advanced ORCC materials. Continued efforts to improve mechanical properties and to develop "one-side" NDE techniques (see technology item 9) will be very beneficial. The process and design allowables should be well documented, and full-scale components should be fabricated and tested.

Low-Weight Ablators

Ablative TPS has been successfully used for manned vehicles. Performance of an ablative system is predictable, and unexpected thermal excursions are not critical. However, no development work has been conducted for this class of material since the Apollo and Viking projects. Aeroassist and direct entry for lunar and planetary missions require high-temperature materials. Also, low weight is required to maximize payload weight and/or decrease cost.

New advanced low density ablation materials should be developed and characterized. Using these materials, subscale TPS should be built and tested in arc-jets to verify performance. Also, analytical models must be updated, then verified. Arc-jet facilities to test large TPS panels (see technology item 13) for certification should be modified.

Special TPS Components

Special TPS components such as joints, fasteners, and seams have had cost and schedule impacts on the Space Shuttle Orbiter. Such components, as well as TPS for moving surfaces, are critical interfaces in all TPS designs. Also, very high heating regions such as nose tips and leading edges require special design considerations including the possible use of heat pipes or mass addition cooling techniques. Research programs tend to address acreage applications at the expense of such "generic" details as gaps and fasteners, leaving the solution of these problems to the more costly development phases of hardware programs.

Advanced special TPS components must be designed, fabricated and tested. Their efforts should be coordinated with concept design efforts under technology items one through five. Design studies of proposed vehicles/missions to determine potential need for and/or benefits of heat pipe/mass addition cooling techniques for regions of local, intense heating should be conducted. Components for most promising applications should be developed and demonstrated. Modify facilities for testing of these TPS components (see technology item 13) should be modified.

TPS / Structural Integration

Better integration of TPS and structure offers the potential of damage tolerant, oxidation-resistant, lightweight systems with lower acquisition and operational costs. One concept consists of continuous fiber-reinforced ceramic matrix composite (CMC) face sheets bonded to a RSI core that is hard bonded to a load-bearing structure of CMC or graphite/polymide. This combination combines the oxidation resistance, durability, and strength of CMC materials with the low weight and good insulation capabilities of RSI. Other concepts utilizing other material combinations also offer potential benefits.

Promising materials, concepts, and applications must be identified. Material characterization tests for new materials will need to be performed, and appropriate analysis codes should be developed and identified. Processing/ fabrication methods should be developed and radiant heating and arc-jet screening tests to determine concept feasibility should be performed.

Water-Based Composite TPS and Structures

Highly-innovative concepts may be needed to meet the weight and cost goals of SEI-type missions. The synergistic use of on-board resources minimizes weight to orbit. For example, water-based polymer or ice matrix composites, which are non-toxic systems, could utilize resources now considered expendable. Deployment and rigidization of such a system would minimize manpower and energy for on-orbit fabrication of aerobrake structures.

Studies of water-based polymer/ice matrix composites must be performed to determine properties, processes, and fabrication techniques for such materials. Representative concepts should be fabricated and tested. Deployment and rigidization on orbit should be demonstrated on Shuttle or Space Station Freedom.

Inspection, NDE and Smart Materials

Current technology is typified by an inability to determine the amount of oxidation/damage in RCC as installed on the Orbiter; suspect RSI bond conditions require removal and replacement; current NDE/bond verification is limited by schedule and funding (and this limitation in turn adversely affects program schedule and cost); on-orbit inspection is impractical. The desired technology level calls for designs that allow for self-analysis of the material using NDT/NDE or smart instrumentation within (or attached to) the material.

NDT/NDE should be developed during original design and manufacture of hardware. Failure indicators should be designed into the material. Tests will be necessary to verify that NDE/NDT indicators performance is acceptable.

Simplified Certification/Recertification Procedures

The present method of certification and recertification is complex, costly and time consuming. The OEX program provided a means to certify without extensive certification effort. Certification by similarity is not used as extensively as it could be. The existing certification policy was a major contributor to the decision to not use advanced TPS concepts on the last orbiter built despite their many offered benefits indicated by all research efforts.

OEX development techniques should be extended for certifying new materials, and modeling/analytical methods for structural changes/modifications should be used. Documentation requirements should be changed so that changes at sub-levels are allowed rather than "treeing" into total package. Recertification requirements as affected by changes in mission requirements should be standardized. In non-critical areas, certification by familiarity is recommended.

Environmental Compatibility

A need to improve weatherproofing of TPS against terrestrial environments exists as evidenced by the following:

- Rain and tap water absorption increases launch weight and causes freeze damage to TPS.
- Hail and ice impacts erode TPS, causing loss of TPS integrity.
- Some fuels, vapors, etc. are incompatible with TPS materials.

Seals and flow paths to preclude absorption of moisture in internal insulation (see technology item 6) are needed. Coatings or outer face sheets resistant to impact damage, impermeable to water intrusion, and capable of surviving the entry thermal environment should be developed. Design studies of new or modified facilities to protect space transportation vehicles for the environment may be required.

The knowledge based on long-term space environmental durability is small, although it is increasing as results are obtained from analyses of the Long Duration Exposure Facility. Atomic oxygen attacks polymer materials and coatings, radiation may degrade materials including coatings and films, and particle impacts can damage TPS. This item could be an enabling technology for planetary missions.

The long term effects of vacuum, atomic oxygen, debris/dust impact, and radiation on materials must be determined. The compatibility of proposed TPS materials with other spacecraft system materials and fuels should be determined. Protective systems (improved materials, shields, coatings, films, etc.) should be developed and TPS performance in appropriate environments and for appropriate duration to provide acceptable design margins need to be evaluated.

On-Orbit Activities

The Entry Systems panel expects that TPS structures for planetary missions will have to be deployed/erected and serviced on orbit due to the size of the vehicles for planetary missions and the size of constraints of Earth-to-orbit launch vehicles. Virtually no experiments have been performed in space to date. Thus, this item is an enabling technology for planetary missions.

A technology program similar to the program developed for large space structures, including Space Station, needs to be developed and implemented. Ground simulations of deploying/erecting and servicing TPS for vehicles for planetary missions must be devised and used to evaluate various concepts and techniques. The ground testing program must be followed by flight experiments similar to the MAST experiment on the Shuttle Orbiter conducted in the mid 1980's, but with a focus on assembly of TPS/structure for proposed vehicle concepts for planetary missions such as an aerobrake. On-orbit-assembled TPS hardware should be returned to ground for inspection and arc-jet testing to assure that the required thermal performance was obtained for hardware that was assembled on-orbit.

Test Facilities

No new arc-jet facilities have been activated in the past 20 years. Some facilities, such as those at Langley Research Center, have been decommissioned. Existing operational arc-jet facilities are inadequate for testing large TPS arrays at representative conditions. Existing arc-jet instrumentation is limited to intrusive flow measurements. There are no facilities that would provide the proper on-orbit simulation for ground tests for assembly of various concepts and techniques.

To adequately meet the experimental needs of technology development and hardware demonstration efforts, upgrades of existing arc-jet facilities and associated instrumentation are needed. Facilities should be improved to:

- Accommodate large size TPS arrays
- Provide uniform high quality flow
- Provide combined radiative and convective heating
- Provide appropriate planetary gas compositions (Mars, Venus, Titan)

Instrumentation should be developed to measure:

- Tunnel flow conditions and intrusive flow methodology
- Test article strain at elevated temperatures
- Surface temperature distribution
- Aero/acoustic environment

Facilities to adequately simulate conditions for evaluation of the viability of various TPS/structure concepts for on-orbit assembly should be devised and built.

Interdisciplinary Modeling Codes

For advanced thermal protection materials and concepts optimum TPS with adequate performance considering all requirements can best be obtained by use of interdisciplinary codes with the capability to consider:

- Micro-level material effects
- Materials response
- Coupling to advanced CFD codes for complete system response modeling
- TPS/structure thermal and structural response
- Life predictions
- Aeroelastic response
- Design optimization

Such codes do not exist. Specific analysis codes, such as ablative modeling codes, are 10-20 years old, and other codes such as those required for analyzing micro-level material effects are only beginning to evolve.

The first essential step is to establish a working relationship between the CFD, CSM, computational materials, and structural optimization communities. The next step is to build on the existing methodology for interdisciplinary codes, such as those evolving for aeroelastic and strength optimization and integrated flow/thermal/structural analysis. Significant computational resources must be available to support code development. The final necessary step is to generate the required benchmark data for validation of the multidisciplinary code.

10.2 RECOMMENDATIONS

In addition to identifying the fourteen technology items described above, which define in essence "what we need to do," the Entry Systems Panel discussed issues related to "how we do it." The following items summarize this discussion:

- Technologists tend to overlook mundane problem areas, which is why we still struggle with problems such as accessibility to equipment and structures for inspection and servicing, weatherproofing of TPS, and extensive checkout operations.

- A gap between technology products and program needs often exists. Advanced development programs should be supported (funded) to bridge this gap, or the technologist should make his products readily useable by the system developer and the system user.

- Cultural and programmatic barriers to efficient technology transfer exist. Responsible and dedicated NASA-wide working groups are recommended for various disciplined to plan specific programs. A step in this direction was the Ames-Johnson group effort on RSI and the Langley-Johnson group effort on carbon-carbon, but technology transfer can still be improved, especially before NASA commits to a project and the clock has started.

- Entry Systems test facilities in the U.S. are aging and must be upgraded. Flight test "facilities" are also needed. SEI cannot succeed without efficient, cost effective test facilities with realistic test environments.

- Certification for space-based/long duration flight entry systems will be a major issue and will need to augment our current methodology to accommodate it.

10.3 PRESENTATIONS

10.3.1 Space Assembled Entry Systems Certification

by Donald M. Curry, NASA JSC